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Organizations like the United States Army allocate large budgets over diverse programs to achieve their vision and objectives. Each organizational element focuses on developing and advocating the best programs to meet their individual objectives and some are resistant to transformational change. As the vision and strategy changes, some senior decision-makers are concerned that their resource allocation processes are not responsive to their transformation objectives. This paper five possible resource allocation methods and recommends the use of Multiple Objective Decision Analysis as the most appropriate resource allocation technique to support organizational transformation.

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# Alternative Resource Allocation Techniques

**OPERATIONS RESEARCH CENTER OF EXCELLENCE**
**TECHNICAL REPORT #DSE-TR-02-05**


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**August 2002**


The Operations Research Center of Excellence is supported by the Assistant secretary of the Army (Financial Management & Comptroller)


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## Abstract

Organizations like the United States Army allocate large budgets over diverse programs to achieve their vision and objectives. Each organizational element focuses on developing and advocating the best programs to meet their individual objectives and some are resistant to transformational change. As the vision and strategy changes, some senior decision-makers are concerned that their resource allocation processes are not responsive to their transformation objectives. This paper five possible resource allocation methods and recommends the use of Multiple Objective Decision Analysis as the most appropriate resource allocation technique to support organizational transformation.

## Acknowledgements

This research report is based on the research of four United States Military Academy Class of 2002 Systems Engineering Majors: Vincent Antoniotti, Calvin Hutto, Will Reynolds, and Victor Jaffett in their capstone project courses. Their efforts and enthusiasm contributed significantly to the success of the project.

Our study clients, COL Bruce Palmatier, LTC Norman Pugh-Newby, and MAJ Victor Badami supported this research. COL Palmatier was chief of the Resource Analysis and Integration Office in Headquarters, Department of the Army, Deputy Chief of Staff for Operation (DAMO-ZR). They provided the idea for the research, essential data for the research, and valuable guidance throughout the project.

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# Chapter 1: Introduction

## *Introduction*

This paper is an extension of research begun by a senior capstone design team in the Department of Systems Engineering at the United States Military Academy at West Point, NY (Antoniotti and others, 2002) under the guidance of the authors. We were asked by the Department of the Army Management Office for Resource Analysis and Integration (DAMO-ZR) to develop alternative methods for evaluating and prioritizing the Army's programs. The office is on the U.S. Army Staff at the Pentagon and is responsible for prioritizing programs to support Program Objective Memoranda (POM) decision-making. COL Palmatier, the Resource Analysis and Integration Division Chief, asked us to develop "an objective, credible, and traceable process to prioritize Army programs." He also requested that we use optimization to determine the best resource allocation.

## *Fundamental Operations Research Problem*

The fundamental reason to prioritize programs (or projects) is to decide which to fund in a budget constrained environment. If we can develop a function that maps the project's level of funding to a project value, we can formulate the resource allocation problem as an optimization model. If each project has an associated value and a budget, the decision variables, objective function, and constraints naturally follow. A binary decision variable represents whether or not a project is funded. The objective is to maximize the total value of the funded projects. The problem is constrained by the budget: the sum of the budgets of funded projects must be less than the total budget. A more sophisticated approach would allow projects to be partially funded. Again the decision variables, objective function, and constraints would naturally follow. In this formulation, decision variables represent the each project's funding level. The objective

is to maximize the total value of the funded projects at their selected funding levels. This problem is also constrained by the total budget. These models can be solved with existing algorithms and software. However, the operations research model does not fully capture the complex environment in which large organizations make resource allocation decisions.

### *Desired Characteristics of a Resource Allocation Technique*

Based on our research and interviews with our client, we have organized the objectives for selecting the best resource allocation technique into the following objectives hierarchy (Figure 1).

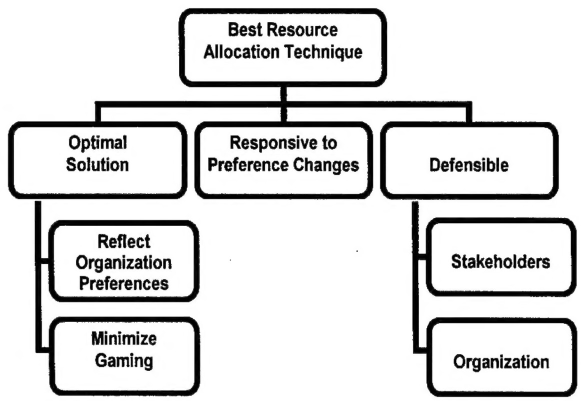


**Figure 1. Resource Allocation Technique Objectives**

**Optimal Solution.** Per the client's request, the resource allocation technique should determine an optimal solution that meets the organization's objectives. Since the fundamental operations research problem is well understood, finding an optimal solution for a given model should be feasible. The challenge will be ensuring that the technique actually reflects the leaderships' objectives and preferences. The technique must capture the value of each project at a budget level. A technique that provides incentives for "gaming the technique" is not desirable. For this reason, minimizing gaming is a sub-objective.

**Responsiveness to Preference Changes.** The resource allocation technique should be transparent enough that decision-makers can easily see how their preferences are reflected in the model and in the resource allocation results. The decision-makers should be able to make preference changes and quickly see the resource allocation changes. This responsiveness serves two purposes. First, it allows decision-makers or reviewers who are not completely comfortable with the model preferences to determine how sensitive the decision is to the existing preferences and whether or not they should invest more time in assessing preferences. Second, preferences may evolve or change abruptly as a result of changes in the environment or a change in the actual decision-maker. The resource allocation technique should be responsive to both of these preference issues.

**Defensible.** The resource allocation technique should be technically credible to operations research experts. We used this desired characteristic as a constraint to eliminate some decision support techniques. In addition, successful large public organizations ensure that the organization's decision-makers and stakeholders believe that the resource allocation process is credible, objective, and defensible. Stakeholders are important individuals that have the ability to influence or block the resources provided the organization. Defensibility is improved if the technique documents a credible rationale for the resource allocation decisions.

### *Overview*

In the next chapter we describe and examine five resource allocation techniques that could be used to evaluate and prioritize Army programs.

# Chapter 2: Five Potential Resource Allocation Techniques

Decision-makers face resource allocation decisions year after year in organization after organization. The critical challenge is determining each project's value in a credible, objective, and traceable manner. We examine several techniques and conclude with some suggestions for developing a technique that not only achieves "an objective, credible, and traceable process to prioritize Army programs," but one which gives the decision-makers the confidence that their objectives and preferences are clearly reflected in the model and that the model identifies the best alternatives for the organization.

### *Relative Benefit Technique*

The Marine Corps Program Prioritization System (PPS) was implemented by the Marine Corps during the 1980s (Buede and Bresnick, 1992) and is still in use. This resource allocation technique assigns a relative benefit (value) to each project. Initially the projects are divided into groups and the groups organized in a hierarchy. At the lowest level, each project in a group is assigned a benefit relative to the best project in the group - the most valuable project within the group is assigned a benefit of 100; a project that is half as valuable receives a benefit score of 50. Only the best projects in each group are considered at the next higher level where an honest broker panel assigns benefits to the best projects using the same process. After assigning benefits at each level, an overall project benefit can be calculated using the relative benefit ratios.

A simple example illustrates the technique. Five projects are grouped into three categories. The initial relative benefits are shown in the lower tier of the hierarchy in Figure 2. The higher tier of the hierarchy shows the relative benefit ratio of the highest benefit projects for

each of the three groups. Project 5 has the highest benefit. Project 4 is assessed at 65% of the benefit of project 5 and project 1 is assessed at 25% of the benefit of project 5. The final project benefit is the original benefit times the relative benefit ratio. Sample calculations for overall benefit using this example with two levels follow in Table 1:

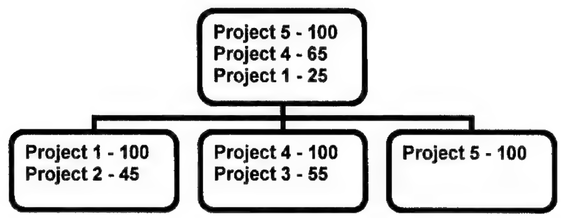


**Figure 2. Relative Benefit Scoring**

| | Level 1 Benefit | Level 2 Benefit | Ratio | Overall Benefit |
|---|---|---|---|---|
| Project 1 | 100 | 25 | .25 | 25.0 |
| Project 2 | 45 | | .25 | 11.2 |
| Project 3 | 55 | | .65 | 35.8 |
| Project 4 | 100 | 65 | .65 | 65.0 |
| Project 5 | 100 | 100 | 1.00 | 100.0 |

**Table 1. Relative Benefit Sample Calculations**

With an overall benefit and a budget for each project an optimization model constrained by the total budget can identify which projects provide the most total benefit for a given budget. The total benefit, b, can be calculated using the equation below. The binary decision variable is $y_j$ for the $j^{th}$ of p projects. The benefit of each project is $b_j$. Optimization can be used to determine the best resource allocation.

$$b = \sum_{j=1}^{p} y_j b_j$$

**Assessment:** The Relative Benefit technique is the simplest of the five techniques we examined; the straightforward assignment of relative benefit and calculation of overall benefit make it a traceable technique for explaining how a decision was reached. However, the Relative Benefit technique raises several issues.

- Ideally, the relative benefit assigned to projects within a group should reflect the project's contribution to the organization's objectives. However, there is no explicit basis for the assessment of benefit (value).

- If the person assigning benefit wants to maximize the funding level for his group, he is likely to "game the system" and exaggerate the benefit for all his projects. Regardless of the ratio assigned at the next level, the overall benefit of his projects will increase. Since there is no objective basis for assigning benefit, it is difficult to detect gaming.

- Since objectives are not explicit in the model, it is difficult to respond to leadership preference changes. A change in decision-maker preferences may require a reevaluation of all of the relative benefits.

The next technique generalizes this technique.

### ***Partial Funding Relative Benefit Technique***

In 2000 the Unites States Air Forces in Europe developed an approach for their resource allocation challenge (Lorenz and others, 2001). We call this technique the Partial Funding Relative Benefit technique because it expands the Relative Benefit technique to allow partial project funding. In addition to the relative benefit of a fully funded project, the project manager must also assess a partial funding benefit function for each project. This function is shown in Figure 3.

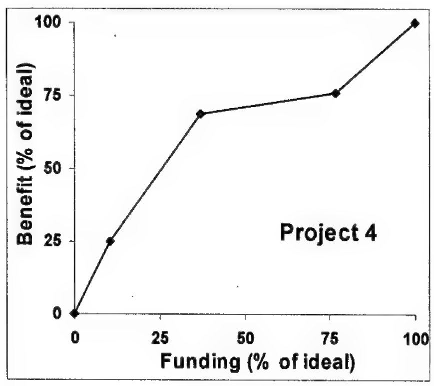


**Figure 3. Partial Funding Benefit Function Example**

This function may be difficult to assess since there are many ways to partially fund a project. In theory, the curve in Figure 3 represents the efficient frontier of all the possible ways to partially fund the project. These functions can be used with an optimization model to determine the optimal resource allocation. In the equation below, $f_p$ represents the percentage funding of each individual project, j. The weights ($w_j$) can be assessed for each project using the relative benefit ratio described in the Relative Benefit technique.

$$b(f) = \sum_{j=1}^{p} w_j b_j(f_j)$$

**Assessment:** The Partial Funding Relative Benefit technique is more complex that the Relative Benefit technique. However, the partial funding benefit function and benefit calculation make it a traceable resource allocation technique. This technique raises several issues.

- The technique is technically credibility if the partial funding benefit function identifies the highest benefit possible for each funding level. Determining this efficient frontier may be difficult and time consuming.
- Like the Relative Benefit technique, there is no explicit, objective basis for determining each project's partial funding benefit function. The functions may be gamed by project managers by making the curves flat at high percentage funding levels. The flat curves can result in a very small budget reallocation (Lorenz and others, 2001).
- Since objectives are not explicit, a change in decision-maker preferences may require a re-evaluation of all of the partial funding benefits functions.

The next technique uses Multiple Objective Decision Analysis.

### *Multiple Objective – Additive Value Technique*

Another common approach to assigning value to each project is to use Multiple Objective Decision Analysis using an additive value model (Keeney and Raiffa, 1976, Keeney, 1992, and Kirkwood, 1997). Other value models are available but the additive value model is by far the most common. This approach has been used in several resource allocation applications (Parnell and others, 2002; Parnell and others, 2001; Parnell, 2001; and Newman and others, 2000). Using this approach a value is assigned for each project by measuring it against the leaderships'

objectives. For each objective, one or more evaluation measures are identified. Next, value functions are developed to define the returns to scale for each evaluation measure. Finally, weights are assessed to capture tradeoffs between evaluation measures.

The technique is illustrated with the notational hierarchy in Figure 4. The single dimensional value function (Figure 5) converts each of the n evaluation measure scores ($x_i$) to a value, $v_i(x)$. Weights ($w_i$) are assessed for each evaluation measure. The total value of the p projects is calculated using the following equation:

$$v(x) = \sum_{j=1}^{p} y_j \sum_{i=1}^{n} w_i v_i(x_{ij})$$

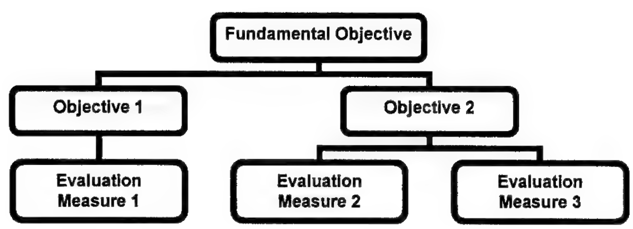


**Figure 4. Objective and Evaluation Measure Hierarchy Example**

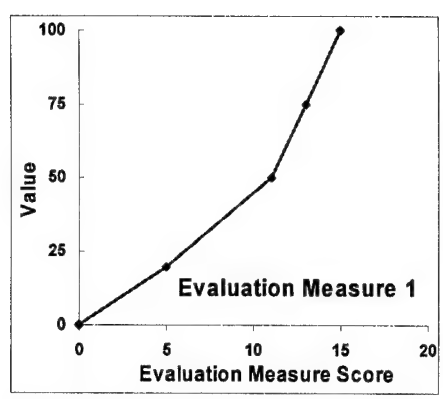


**Figure 5. Single Dimensional Value Function Example**

Typically a large organization has many objectives and many measures, however, projects usually score well with respect to only a few of the measures. In several of the cited references, optimization was used to determine the best resource allocation. Projects can be scored at different funding levels and a constraint can be added to insure that only one funding level is possible.

**Assessment:** The Multiple Objective – Additive Value technique is that applies the concepts of Value Focused Thinking (Kenney, 1992). The value model defines the objectives of the organization and the how achievement of the objectives is measured. Value Focused Thinking encourages project leaders to use the value model to develop projects that better meet the organization's objectives. The technique is technically credible and provides a defensible basis for resource allocation. The evaluation measure scores, value functions, weights, and the objectives make the project value defensible to decision-makers and stakeholders. Gaming is difficult since the objectives, value functions, and measures are obtained from customers and not project personnel. Experts can verify the scores since projects are scored on either a natural or a constructed scale. Responding to preference changes is easy because preferences are captured in weights and value functions. The effects of preference changes on resource allocation can be quickly seen. However, two issues arise with this method.

- It is challenging and time consuming to determine the objectives, identify evaluation measures, develop single dimensional value functions, and capture the weights. The scoring process also takes time.

- An additive value model assumes preferential independence. This is technical issue is not a factor in most decision analysis applications (Kirkwood, 1997).

### *Partial Funding Relative Pain Technique*

COL Bruce Palmatier proposed this technique in our initial project meeting. The idea is that the objective of resource allocation in a very budget constrained environment is to minimize the total pain (or risk) to the organization. The key question is "how much does it hurt if your funding is reduced?" This technique is similar to the Partial Funding Relative Benefit technique with benefit replaced by pain. The project manager (or decision-maker) assesses a partial funding pain function (Figure 6) instead of a partial funding benefit function. Project managers may be more comfortable assessing the partial funding pain functions since in some cases it may be easier to determine how much pain is incurred as funding is decreased.

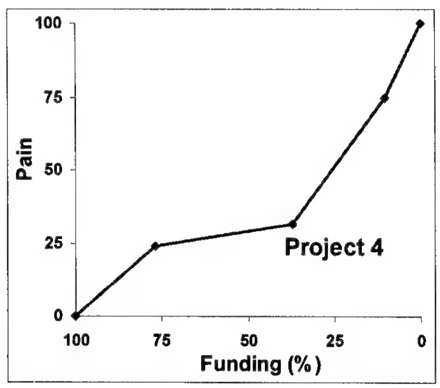


**Figure 6. Partial Funding Relative Pain Function Example**

The Partially Funding Relative Benefit and the Partially Funding Relative Pain optimization models are mathematically equivalent but we replace the benefit functions with the pain functions. The weights ($w_j$) can be assessed for each project using a relative pain ratio similar to the relative benefit ratio.

$$p(f) = \sum_{j=1}^{p} w_j p_j(f_j)$$

**Assessment:** The Partial Funding Relative Pain assessment is similar to the Partial Funding Relative Benefit assessment. The partial funding pain function and pain calculations make it a traceable resource allocation technique. However, the technique raises several issues.

- The technique's technical credibility relies on the partial funding pain function being the efficient pain frontier. Determining the efficient frontier may be difficult and time consuming.

- There is no explicit, objective basis for determining a project's partial funding pain function. The functions may be gamed by project managers by making the curves steep at high percentage funding levels.

- Since preferences are not explicit, a change in decision-maker preferences may require a re-evaluation of all of the partial funding pain functions.

- The pain function may be a more appropriate perspective in a stable environment, a constant organizational strategy, and small reductions in total budget. It is not clear how one would use the pain approach in a major budget increase environment. Also, it may be more difficult to define pain when an organization is undergoing significant change.

The final technique combines two of the techniques we have considered.

### *Partial Funding Measure Pain Technique*

This technique was developed by the authors to address some of the issues of the Partial Funding Relative Pain technique. The technique is a combination of the Partial Funding Relative Pain and the Multiple Objective-Additive Value techniques. We use two functions. The first function is a measure pain function (Figure 7). The evaluation measure is mapped to relative

pain by answering the question "How much does this project suffer if the evaluation measure is changed?" One evaluation measure pain function must be identified for each project.

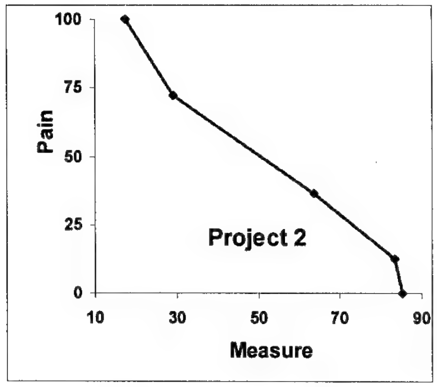


**Figure 7. Measure Pain Function Example**

This technique uses a second function that maps funding levels to the evaluation measure scores for every project. This measure function (Figure 8) must be the efficient frontier of all possible partial funding concepts. It is similar to the idea of response functions presented by Kirkwood, 1997.

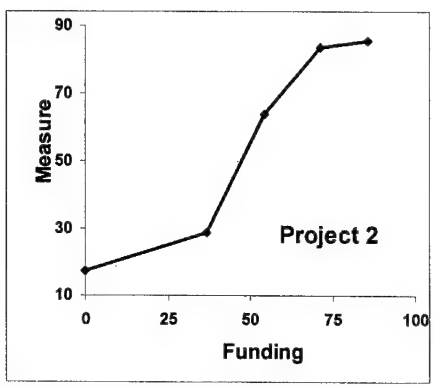


**Figure 8. Measure Function Example**

These functions can be used with an optimization model to determine the optimal resource allocation. In the equation below, $f_j$ represents the percentage funding of each individual

project, j. The measure function $m_j(f_j)$ represents the evaluation measure score at funding level $f_j$. The pain function is $p_j(m_j(f_j))$ represents the pain at funding level $f_j$ for project j. The weights ($w_j$) can be assessed for each project using a relative pain ratio similar to the relative benefit ratio.

$$p(f) = \sum_{j=1}^{p} w_j p_j(m_j(f_j))$$

**Assessment:** The Funding Measure Pain technique addresses some of the Funding Relative Pain Technique issues. The partial funding measure function and the measure pain function make it a traceable resource allocation technique. However, the technique raises some issues.

- The technique's technical credibility relies on the partial funding measure function being the efficient frontier. Determining the efficient frontier may be difficult and time consuming.
- It may be difficult to capture the pain of the project in only one evaluation measure.
- The pain function may be a more appropriate perspective in a stable environment, a constant organizational strategy, and small reductions in total budget. It is not clear how one would use the pain approach in a major budget increase environment. Also, it may be more difficult to define pain when the organization was transforming to a new strategy.
- Preferences are expressed in tradeoffs between measures for different projects. It may be difficult to weight project preferences based on the levels of one pain evaluation measure.

This completes our examination of the five alternatives for resource allocation project evaluation. The final chapter provides our conclusions and recommendations.

# Chapter 3: Comparison Of Alternatives and Recommendation

Large public organizations seek a rational way to allocate their budgets. They desire a resource allocation technique that supports their organizational objectives, is responsive to changes in preferences, and is defensible. Each of the techniques we examined, given that decision-makers' preferences are properly reflected, will find a good resource allocation plan. However, we believe that some techniques will determine a better plan, some will respond better to preference changes, and some are more defensible.

We compare the five techniques against the three objectives and five criteria shown in Figure 1. In Table 2 we show our evaluation of the techniques using a red (does not meet the intent of the criteria), yellow (might meet criteria with enough management attention), and green (satisfactorily meets criteria). Next we describe our evaluation for each of the three objectives.

| Resource Allocation Technique | Optimal Solution | | Responsive to Preference Changes | Defensible | |
|---|---|---|---|---|---|
| | Reflect Organizational Preferences | Minimize Gaming | | Stakeholders | Organization |
| Relative Benefit | G | Y | R | R | Y |
| Partial Funding Relative Benefit | G | Y | R | R | y |
| Multiple Objective - Additive Value | B | G | G | G | G |
| Partial Funding Relative Pain | G | Y | R | R | y |
| Partial Funding Measure Pain | G | G | R | Y | G |

Red = does not meet the intent of the criteria
Yellow = might meet criteria with enough management attention
Green = satisfactorily meets criteria
Blue = exceeds criteria

**Table 2. Resource Allocation Technique Evaluation Matrix**

### *Optimal Solution Evaluation*

If properly done, each of the five techniques can reflect organizational preferences. Applying the concepts addressed in Value Focused Thinking (Keeney, 1992) to the Multiple Objective - Additive Value technique will enhance the technique's ability to determine an optimal solution by ensuring that preferences are captured through the definition of objectives (qualitative value model) and the quantification of achievement of the objectives (quantitative value model). Multiple Objective- Additive Value and Partial Funding Measure Pain are the only techniques that minimize gaming since they both use objective measures instead of subjective relative benefit or pain assessments.

### *Responsiveness to Preference Changes Evaluation*

The Multiple Objective – Additive Value technique is most responsive to changes in preferences. Changes to preferences are easily made by adjusting value model weights and value curves. These do not depend on the number of projects. All the other techniques require reassessment of the functions and weights of each project impacted by the change in preference. This does not meet the client's goal of being able to quickly show the impact of preference changes..

### *Defensible Evaluation*

The defensibility of a technique depends on the degree to which the technique is perceived as a credible, objective, and traceable rationale for resource allocation. The two techniques with objective measures meet the criteria for defensibility within the organization. The subjective relative benefit/pain techniques may meet the criteria if the leadership has confidence in each individual that made the project assessments. The Multiple Objective – Additive Value technique has also been shown to be defensible to stakeholders in numerous

applications. Since Funding Measure Pain is a new technique it may not have acceptance with stakeholders.

### *Additional Evaluation Considerations*

Two additional considerations impact the selection of the best resource allocation technique for the Army: the time to implement the technique and the appropriateness of the technique in the current defense environment.

The only major issue with Multiple Objective Decision Analysis identified in our study was the time to implement the technique in a large organization. Senior leaders must be interviewed and buy into the process. The qualitative value model must be vetted with the senior leadership to insure that the organizational objectives reflect their vision. In addition, the development of the quantitative value model requires access to a large number of technical experts to ensure the best evaluation measures are used and the value functions capture customer values. Finally, the project scoring requires access to project experts. Once the initial process is implemented, the subsequent use of the process requires much less time.

The second issue is the defense environment. The pain techniques are most appropriate for stable organization in a slowly changing environment responding to a budget reduction. If an organization is undergoing substantial change (as is the U.S. Army during its current Transformation), the use of Value Focused Thinking concepts with the Multiple Objective – Additive Value technique will help the organization identify and clarify its objectives. We believe this is the only technique that would allow an organization to break free of its traditional resource allocation strategy and move forward with a new vision.

### ***Recommendation***

Based on our analysis of the five alternatives, we recommend the client prototype the use of the Multiple Objective – Additive Value technique for the Army resource allocation process. The technique dominated the other four techniques in the five evaluation criteria. We believe that the potential for helping the Army transform to a new vision far outweighs the resources that are required to implement the technique.

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# Appendix A: List of Abbreviations

| | |
|---|---|
| CSA | Chief of Staff of the Army |
| OGT | Option Generation Table |
| ORCEN | Operations Research Center |
| PEG | Program Evaluation Groups |
| POM | Program Objective Memoranda |
| SE | Systems Engineering |
| TOA | Total Obligation Authority |
| QDR | Quadrennial Defense Review |
| USMA | United States Military Academy |

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